NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Impacts of Climate Change on Pinyon Pine Cone Production

by
Miranda D. Redmond and Nichole N. Barger
Department of Ecology and Evolutionary Biology
University of Colorado, Boulder

Photo 1. Pinus edulis cone and seeds.

Part I – Introduction to Pinyon Pine and Mast Seeding

Pinyon pine (*Pinus edulis*) is a semi-arid pine species that is common throughout the southwestern United States. This species provides a range of ecosystem services to humans and critical habitat to a variety of wildlife species (Brown et al., 2001). Pinyon pine has experienced extensive drought and beetle-induced tree mortality over the past several decades (Breshears et al., 2005; Mueller et al., 2005). This recent mortality has raised concern about the potential bottlenecks to pinyon pine regeneration, such as seed availability, with increasing temperatures.

Pinyon pine is a mast seeding species, which means that this species has high annual variability and also high synchronicity in seed production among trees within a stand. In other words, every few years, pinyon pine populations produce very high amounts of seeds (or bumper crops) and then, in other years, pinyon pine populations produce very few seeds. Similar to other semi-arid pine species, such as ponderosa pine, it takes multiple months for cones to mature. First, cones are initiated in late summer, which is when pollen and ovule meiosis occurs. Fertilization then occurs in early summer of the following year, at which time little cones or conelets develop and then over winter. The following fall is when the mature seed cones have formed (approximately 26 months after those cones were initiated).

In this case study, you will learn why mast seeding is common in many perennial plants, how mast seeding in pinyon pine is associated with climate, and how increasing temperatures may affect pinyon pine cone production.

Photo 2. Pinyon-juniper woodland on Wray Mesa in La Sal, Utah.

Reading Assignment

- Kelly, D., and V. L. Sork. 2002. Mast seeding in perennial plants: why, how, where? *Annual Review of Ecology and Systematics* 33: 427–447.
- Forcella, F. 1981. Ovulate cone production in pinyon: Negative exponential relationship with late summer temperature. *Ecology* 62: 488–491.

After reading the two articles above, please answer the following questions. Your answers should be short (50–100 words per question).

Questions

1. Why do many perennial plant species exhibit mast seeding behavior?
2. How can climate affect mast seeding?
3. Based on the findings of Forcella (1981), how might pinyon pine cone production be affected by increasing late summer temperatures?

Photo 3. Crossbill harvesting pinyon pine seeds in Browns Canyon near Salida, CO.

Part II – Hypotheses and Experimental Design

Climate has varied over the past several decades at the study sites that were sampled by Forcella (1981) in New Mexico and northwestern Oklahoma (Figure 1).

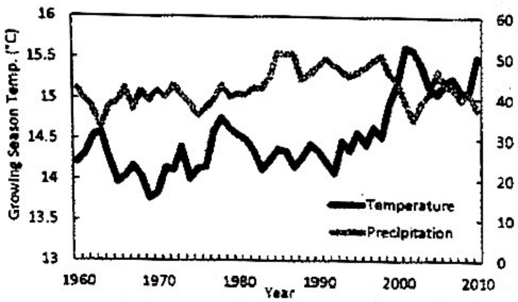

Figure 1. Three-year moving averages of mean growing season (March–October) temperature (black line) and annual precipitation (grey line) from 1960 to 2010 in the pinyon-juniper woodlands sampled by Forcella (1981).

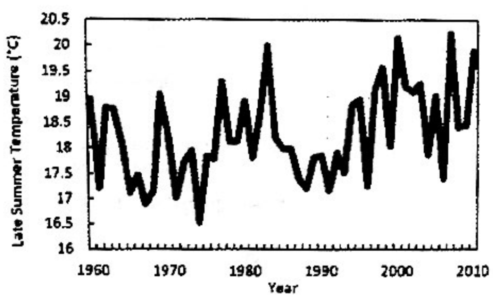

Figure 2. Late summer temperature from 1960 to 2010 in the pinyon-juniper woodlands sampled by Forcella (1981). Climate data are from the PRISM Climate Group and were averaged across all sampled sites.

Assignment

1. Develop a hypothesis of how changes in climate over the past several decades may be affecting pinyon pine cone production.
2. Design an experiment to test your hypothesis above. What are some of the limitations? How long of a time period of cone production data is needed?

Part III – Data Interpretation

After reading the findings of Forcella (1981), two researchers at the University of Colorado (M.D. Redmond and N.N. Barger) contacted F. Forcella to do a follow-up study in 2012 (see Redmond et al., 2012). Forcella had sampled sites in 1978 to quantify cone production from 1969–1978 (1974 decade) at study sites in New Mexico and northwestern Oklahoma (Forcella, 1981). In this follow-up study, these researchers went back to nine of the study sites in 2012 that Forcella had previously sampled in 1978. They used the same cone abscission scar methodology to quantify patterns of cone production from 2003–2012 (2008 decade).

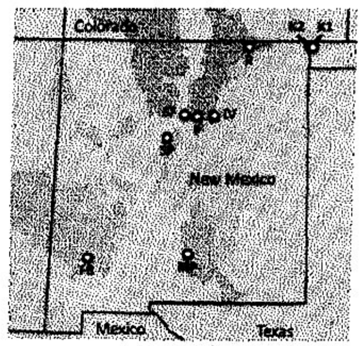

Figure 3. A map of the nine sites sampled (white circles) in 1978 and 2012 in New Mexico and northwestern Oklahoma. Grey shading indicates different ecoregions (EPA Terrestrial Ecosystems Level III Ecoregion Classification), with: two sites, K1 and K2, in the Southwestern Tablelands ecoregion; three sites, R, LV, and P, in the Southern Rockies ecoregion; three sites, SP, MP, and FB, in the Arizona/New Mexico Mountains ecoregion, and one site, SF, in the Arizona/New Mexico Plateau ecoregion.

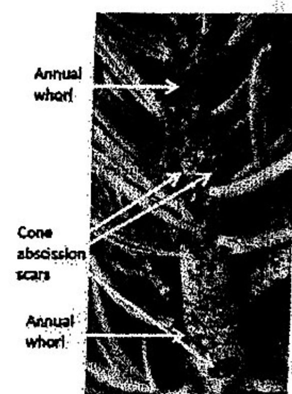

Figure 4. A pinyon pine branch that contains annual whorls and cone abscission scars. Researchers located annual whorls to know the year of each cone or cone scar along the branch. Following, they counted all cone abscission scars and cones and conelets (1st year cones) still remaining on the tree. Please note, cone abscission scars are much larger than needle abscission scars (not shown), and thus are easy to distinguish.

Results

Table 1. Seed cone production across all sites in the 1974 decade (1974) and the 2008 decade (2008).

	Mean no. cones/branch				Frequency of masting events	
	Mast years only		All years			
Site	1974	2008	1974	2008	1974	2008
K2	2.5	2.8	0.8	1.0	2	2
K1	2.7	2.2	1.2	0.9	2	3
FB	2.5	1.3	0.8	0.4	2	2
LV	2.3	1.3	1.0	0.4	2	2
SF	3.5	1.8	0.9	0.3	2	1
SP	3.5	2.1	1.1	0.7	2	3
P	3.5	1.0	1.0	0.4	2	2
MP	3.7	1.1	0.9	0.3	2	2
R	4.9	1.9	0.8	0.5	1	2
Overall	3.2 ± 0.3^{A}	1.8 ± 0.2^{B}	0.9 ± 0.1^{A}	0.5 ± 0.1^{B}	1.9 ± 0.1	2.1 ± 0.2

Notes: Values in the lower row are means ± 1 SE across all sites, with different letters denoting significant differences between the two decades, with $\alpha = 0.05$. In both decades, we calculated mean seed cone production (mean cones/branch) using data from mast years only as well as all years.

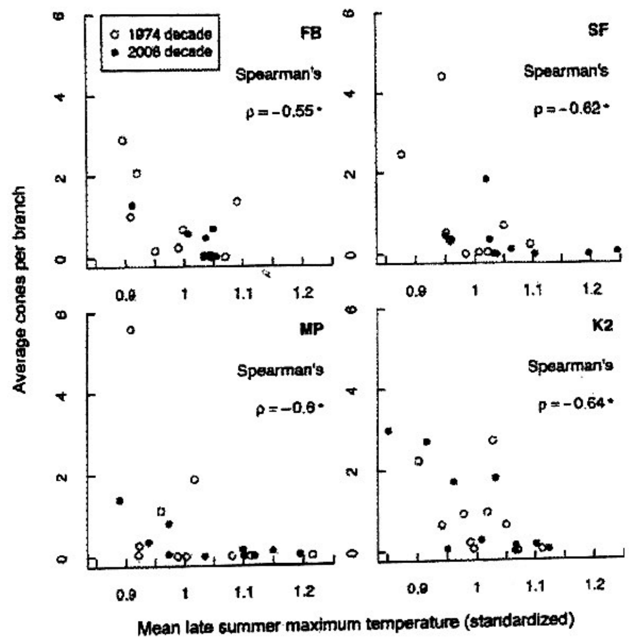

Figure 5. Seed cone production (mean cones produced per branch) and standardized late summer temperature ($Temp_{year\ of\ cone\ initiation}/Temp_{1950-2010\ Avg}$) in the 1974 decade (open blue circles) and the 2008 decade (red closed circles). Each point represents one year of data (i.e., cone production for that year and mean late summer maximum temperature during the year of cone initiation). Data are from 4 representative sites. Data from the other 5 sites can be found in Redmond et al. (2012). Significance levels at $P < 0.05$ of the Spearman's rho are denoted with an asterisk.

- *Average cones per branch (y axis)* is the number of cones (i.e., cone scars) measured per branch on average across all trees within the site for a given year.
- *Standardized late summer temperature (x axis)* is the mean daily late summer (end of August and beginning of September) maximum temperature. This value is standardized across all sites, such that a value of 1 means that late summer temperature for a given year is equal to the 1950–2010 average, while a value > 1 is above average and a value < 1 is below average.
- *Spearman's rho* is a correlation coefficient and can range from −1 to +1, with 0 showing no relationship between late summer temperature and cone production, values closer to −1 showing an increasingly negative relationship, and values closer to +1 showing an increasingly positive relationship.

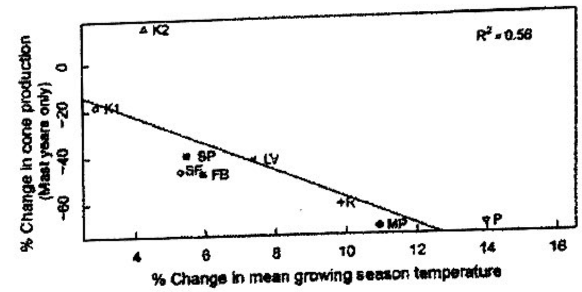

Figure 6. Percent change in seed cone production during mast years from the 1974 decade to the 2008 decade in relation to the percent change in mean monthly growing season (March–October) temperatures during the 3 years prior to seed conelet formation during mast years (slope = −5.86, Adjusted $R^2 = 0.56$, $P = 0.01$). Letters at the right of each symbol indicate the corresponding site.

Questions

1. What does Table 1 tell you about how cone production has changed between the 1974 decade (1969–1978) and the 2008 decade (2003–2012)? Why would it be important to examine how cone production has changed during mast years only (rather than all years)?
2. What is the relationship between late summer temperatures and cone production? What evidence, if any, in Figure 5 suggests that changes in late summer temperatures between the 1974 decade and 2008 decade explain the decline in cone production? What evidence, if any, suggests that late summer temperatures don't explain the decline in cone production?
3. What is the relationship between changes in cone production and changes in growing season temperatures? Why might this relationship exist (provide 1–2 potential explanations)?

Part IV – Summary Task

Although the U.S. market for pine nuts is estimated at 100 million dollars, 80% of pine nuts are imported into the U.S. each year. Pine nuts are the seeds from a variety of different pine trees. Two species of pinyon pine (*Pinus edulis* and *Pinus monophylla*) are the major pine nut producers in the U.S. There are several organizations within the western U.S. interested in developing the pine nut market. There is concern, however, that changing climate will change the potential production of pine nuts in this region.

As an ecologist working in pinyon-juniper woodlands, you have been asked by the New Mexico Pinon Nut Association to make a prediction about how future climate may affect pinyon cone production and which populations may be most vulnerable to these changes. In order to do this, you must now integrate what you learned from the table and figures in Part III and the new information provided in the table below with information from a brief literature search. Your short report should include this information:

(1) A brief description of how climate is predicted to change in New Mexico over the next several decades.

(2) The connection between climate and pine nut production.

(3) A prediction of how future climate may influence pine nut production across an elevational gradient of 1300 m to 2200 m.

Please cite at least one research paper to support (1) and two research papers to support (2) and (3). You may use any of the references cited in this case study. Please feel free to incorporate any tables or figures from the publications you cite to support your report.

Table 2. Temperature and precipitation across all sites in the 1974 decade (1974) and the 2008 decade (2008).

		Growing season temp. (°C)		Annual precip. (cm)		Proportion of cool late summers	
Site	Elev (m)	1974	2008	1974	2008	1974	2008
K2	1295	17.2	18.0	39.5	40.0	0.5	0.5
K1	1426	17.2	18.0	39.5	40.0	0.5	0.5
FB	1950	15.4	16.6	43.1	44.8	0.6	0.5
LV	2054	12.8	14.0	40.7	40.1	0.6	0.5
SF	2072	14.3	15.2	28.8	32.1	0.6	0.3
SP	2160	13.1	14.3	47.5	48.0	0.7	0.6
P	2170	11.9	13.8	34.9	41.2	0.6	0.3
MP	2179	12.1	13.8	47.6	60.1	0.5	0.4
R	2213	12.4	13.6	39.4	41.3	0.8	0.4
Overall		14.0	15.3	40.1	43.1	0.6 ± 0.0[a]	0.4 ± 0.0[b]

Notes: Growing season temperature (March–October) and annual precipitation were calculated as mean monthly temperature or precipitation during the year of cone initiation (2 years prior to mature cone formation) in both decades. The proportion of years with below average (1950–2010) late summer temperatures was calculated using the mean daily maximum summer temperatures during the two week time period most highly correlated with seed cone production at each site (see Fig. 3). Fort Bayard is missing two years of weekly climate data in the 2008 decade and therefore the proportion was calculated using only 8 years. Values in the lower row are means ± 1 SE across all sites, with different letters denoting significant differences between the two decades, with $\alpha = 0.05$.

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Photo 1: *Pinus edulis* cone and seeds, Main Loop Trail, Bandelier National Monument, New Mexico, USA. By S. King, US NPS, public domain, from http://commons.wikimedia.org/wiki/File:Pinus_edulis_cone_NPS.jpg.
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